

# Infant Incubator Project

## A low-cost, low-energy consumption solution for infant incubators in developing countries

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### BACKGROUND AND MEDICAL NEED

Temperature regulation is one of the most important factors affecting survival in newborn infants. Infants typically lose heat to their environment in four different ways: through conduction, convection, radiation, and evaporation. Premature infants, as compared to term infants, are at an even greater disadvantage in temperature maintenance, because of the larger skin surface area to body mass ratio, decreased subcutaneous fat, and low supplies of brown fat.<sup>1</sup> Furthermore, the normal surge in metabolic rate that occurs after birth is reduced in preterm infants, resulting in limited heat production.

Preterm infants' birth rates are especially high in developing countries. A combination of poor facilities, poor after-birth care, and a lack of knowledge have propelled preterm birth to be one of the leading causes of infant mortality in developing countries.

Incubators provide warmth and prevent heat loss to significantly improve survival rates. The use of air-heated incubators has been the

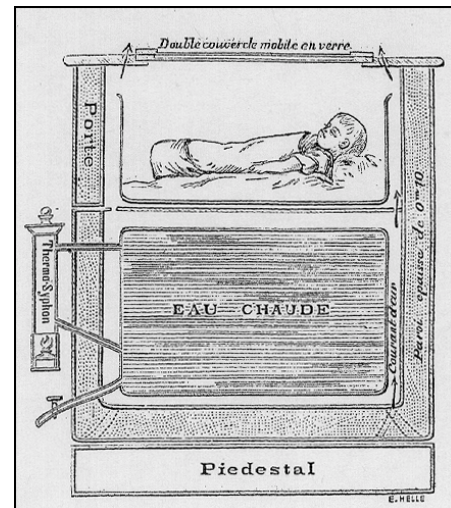


Fig. 1: Incubator developed by Stéphane Tarnier in the 19<sup>th</sup> century reduced infant mortality significantly.

standard method of providing a stable, individualized thermal environment for the newborn infant at risk. One of the very first incubators (**fig. 1**), invented by Stéphane Tarnier in the late 19<sup>th</sup> century, reportedly reduced mortality among infants with birth weights between 1200 and 2000 g from 66% to 38%.<sup>2</sup>

The availability of incubators and radiant warmers in industrialized countries has made neonatal hypothermia uncommon, except in infants transported over long distances. In

<sup>1</sup> Antonucci, R., et al. *The infant incubator in the neonatal intensive care unit: unresolved issues and future developments*. **Journal of Perinatal Medicine**. 37(6): 587-98.

<sup>2</sup> Auvard, A. *De La Couveuse Pour Enfants*. **Archives de Tocologie des Maladies des Femmes et des Enfants Nouveau-nés**. 10:577-609, October 1883.

developing countries, however, hypothermia still poses a significant threat to the survival of low birth-weight and preterm infants. Even where incubators are available, their use is often fraught with operational difficulties. These include maintaining incubator air temperature, air flow and relative humidity within a narrow range in order to provide a thermoneutral environment for the infant being nursed naked. This level of regulation requires sophisticated modern equipment, neonatal intensive care units, highly skilled professionals and a constant electricity supply. The cost of such infrastructure is often prohibitive in developing countries such as Nigeria.<sup>3</sup>

## INADEQUACY OF CURRENT DEVICES

There is currently a wide range of incubators available to developing countries. Although each one is very beneficial in one or more areas, they all have specific areas where they need improvement. Our goal is to find a good balance to try and incorporate these benefits into one single incubator.

One example of a low-cost solution is the Embrace<sup>4</sup> infant warmer. There are many downfalls to this \$25 design. First of all, it does not have any form of temperature control. It also does not have any protection against infections and since it has no light source, it cannot help with jaundice. Lastly, it does not allow for the baby's body to be easily observed, as can be done with more



Fig. 2: Embrace Infant Warmer

traditional incubators, and is extremely important, as many of the infants in the most need of warmth are pre-mature infants, which often face many other complications. Given this downfalls, it is extremely cost efficient, which can sometimes be the determining factor when budgets are thin.

Another example is the "car part"<sup>55</sup> incubator. This solution, while midly low-cost (still \$1,000/incubator), requires working parts from vehicles (and no one wants to take parts from a working vehicle). It also has not been tested for its ability to prevent infections and does not allow direct access to the infant through "sleeves," as does



Fig. 3: "Car-Part" Incubator

many current incubators. It is also fairly complicated to build and does not have a humidifier. The main advantage of this

<sup>3</sup> Ibe, O., et al. *A comparison of kangaroo mother care and conventional incubator care for thermal regulation of infants <2000 g in Nigeria using continuous ambulatory temperature monitoring.* **Ann Trop Paediatr.** 2004 Sep;24(3):245-51.

<sup>4</sup> Embrace. <<http://embraceglobal.org/>>

<sup>55</sup> Center for Integration of Medicine & Innovative Technology. <[http://www.cimit.org/images/programs/GHI\\_Incubator\\_Handout.pdf](http://www.cimit.org/images/programs/GHI_Incubator_Handout.pdf)>

system is that all of the parts should be locally available.



Fig. 4: The Hemel Baby Incubator (HEBI) has been around since the 1968 and is still used in developing countries.

A third example (and the best one we could find) is the HEBI<sup>6</sup> (Hemel Baby Incubator). This incubator costs around \$500, not including the light bulbs, and it must be shipped from the Amsterdam airport. It prevents infections (and claims to do this better than most modern incubators, despite the fact that it's made of wood) and has sleeves to access the infant, but it does not have fine temperature control as it is heated solely by turning on/off the lightbulbs.



Fig. 5: "Suitcase Incubator" used in Haiti after the earthquake of 2010.

Another incubator that was developed for use in Haiti, after the devastating earthquake this past winter was the suitcase incubator.<sup>7</sup> Although there is not much information on how it was made, there are many advantages and disadvantages that can be determined based on this idea. First of all, it is extremely portable, which is more convenient for short-term use, as opposed to a more long-term use in a developing country's hospital. It must be relatively cheap since you would simply use a suitcase as a shell. It is unclear how well insulated this could be, or how well it could circulate the air while preventing infections. Above is an image of these incubators being used at the Project Medishare/University of Miami Field Hospital, in Port Au Prince, Haiti, on Friday, March 19, 2010.

## MATERIALS NEEDED

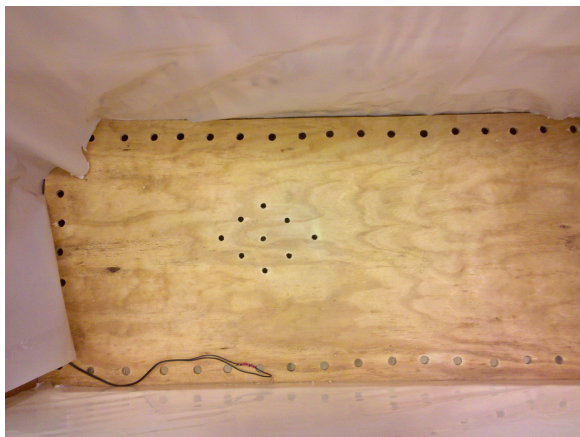
Our incubator will consist of a heater, fans to circulate the warmed air, a servocontrol used to regulate air temperature inside the incubator, a container for water to add humidity, and a power supply. It will have two compartments, a main compartment that will hold the baby along with a small lower compartment. The lower compartment will be used to store the water container and heated air will rise up from here to the main compartment through openings along the inside bottom (fig. 6).

For this project, we have chosen a 12 V, 16.7A power supply. This was chosen because we plan to run everything off 12 V and a higher current is needed to supply heat.

<sup>6</sup> HEBI Org. <[www.hebi-incubator.org/](http://www.hebi-incubator.org/)>

<sup>7</sup> Nunez, E.A. *Miracle in Haiti*. Synapse UNSOM. <<http://www.medicine.nevada.edu/synapse/spring2010/miracle-in-haiti.html>> March 2010.





**Fig. 6: Incubator during development: Openings for warm air to flow upwards.**

For the incubator frame, we have chosen to use wood as opposed to plastic, which is the basis for incubators in most modern, developed countries. We used 5/8" thick plywood for this project. This can be justified in several ways. First, there is an abundance of wood available in all parts of the world, whereas plastic may not be. It is still very durable, and can be comparable in their insulation properties, with heat transfer coefficients ranging from 0.055 to 0.17 at 25 Celsius. In particular, in Africa, there is an abundance of African Mahogany and Teak wood, both of which are more insulating and durable. Wood is much less expensive, easily replaced, and wood is absolutely non-toxic (unless treated with toxic stains, etc). Lastly, wood has less of an impact on the environment and is more sustainable. The main drawback to wood that we have found while talking to physicians (from the US) is that they would be worried about infections. In contrast, the HEBI incubator (made of wood) claims that "The growth of colonies in the Petri dishes put in the Van Hemel Incubator turned out to be significantly lower than in the professional one. This is probably the result of not recycling the air, short pasteurization, dehumidification and the

subsequent humidification of the air."<sup>8</sup> Since our system will be similar to the HEBI in dehumidification/rehumidification and in the lack of reuse of air, we do not foresee any increase in infection rates over modern incubators.

Many current incubators use plexiglass to construct the window through which one can see the infant. For our project, we propose using a more portable, less expensive polyethylene material, made by ULINE (**fig. 7**). This material has thermal properties similar to that of plexiglass, while providing additional features such as UV protection and more adequate sterilization. Because of the thinness of the material, it is also easily transported in large quantities and can easily be sized to fit any custom-sized incubator.



**Fig. 7: Material used in place of plexiglass. It is less expensive, easier to transport, similar insulation, and still transparent, relative to other solutions.**

As a heat source, we have chosen a small car heater. This was chosen for it's relatively low power consumption (150 W) it's compactness, and because it is widely available in 12 V, to make for easier integration with the rest of the incubator.

<sup>8</sup> HEBI Org. < <http://www.hebi-incubator.org/templates/hebi/global/index.php?lngid=2&sqlmode=1&fid=389>>

Heaters like this are readily available around the world or easily transported anywhere.

To maintain a desired relative humidity, we have added a common baking pan to hold water in the lower compartment. As the incubator heats up, the water will slowly evaporate and rise to provide a more humid environment to the infant. This is necessary because the increased heat would otherwise dry out the air. We have covered the pan and added slits to the top to allow for a more controlled level of humidity.

We used the MX052 digital temperature controller, which allows a range of  $-20$  to  $100^{\circ}\text{C}$ . Since for this project, we want to maintain air temperature that is about that of body temperature, we will be using the upper end of this spectrum, and can be accurate to within  $0.1^{\circ}\text{C}$ . In particular, we will maintain a temperature between  $36.5$  and  $37.5^{\circ}\text{C}$ , as found in literature.<sup>91011</sup>

For air circulation in our incubator, we believe that using old PC fans may be more cost efficient and locally available than other solutions. This is because the turnover rate for computers is extremely high, and there is an abundance of old computers that still contain perfectly working parts. As an additional plus, PC fans do not consume an excess of power, they run off  $12\text{ V}$ , and should generally be free of cost, since most people find old computers ( $> 10$  years old) useless.

Another goal of this project was to make this product easy to build and use, while fulfilling the previously mentioned goals of reduced costs and lower power consumption. Since there are overall not many pieces to put together and the instructions for constructing the incubator are fairly simple, we feel that this device could be easily replicated, with any amount of small modifications to account for locally available products. Once the incubator has been built, the wood may need to be replaced after many years of use, and the water replaced daily. Electronic parts need only be replaced on a case-by-case basis, and the digital output will always inform you of the current temperature inside the incubator as well as the minimum temperature and maximum temperature allowed.

The next page lists all the materials used, as well as their prices.

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<sup>9</sup> Ducker, D.A., et al. *Incubator temperature control: effects on the very low birthweight infant*. **Archives of Disease**. 1985. 60:902-907.

<sup>10</sup> Hey, E.N., Katz, G. *The Optimum Thermal Environment for Naked Babies*. **Archives of Disease in Childhood**. 1970. 45(241): 328-334.

<sup>11</sup> Harpin, V.A., Rutter, N. *Humidification of incubators*. **Archives of Disease in Childhood**. 1985. 60:219-224.

Material	Details	Unit Price
<b>Plywood (0.5" or thicker)</b>	1- 36"x30" panel (back) 2- 30"x18" panels (sides) 1- 34.5"x18" panel (main comp. bottom) 1-36"x6" panel (front bottom) 1- 36" x 18" panel (humidity comp. bottom)	FREE! (< \$30)
<b>Support Wood (1.5" x 1.5" in width)</b>	2-36" length (front and back top- for access frame) 4- 15" length (top sides for access frame and main frame) 2-35" length (front and back top- for main frame) 1-31.5" length (front bottom- for main frame) 4-22.5" length (up-and-down corner supports for main frame) 2-5.5" length (front bottom for humidifying compartment)	\$6.10 (Home Depot)
<b>Hinges (2 sets)</b>	For access frame	\$5.96 (Home Depot)
<b>ULINE Polyethylene Window Insulator</b>	In place of plexiglass. 0.004" thickness, clear polysheeting. 0.006" thickness used to further insulate walls.	FREE! (< \$10)
<b>Power Supply</b>	12 V/ 16.7 A	\$100
<b>Heater</b>	Car Heater – 12 V, 150 W	\$9
<b>PC Fans (2)</b>	12 V/ 0.13A	FREE!
<b>Temperature Control System</b>	MX052 digital temperature controller	\$39.99
<b>Water Pan to Maintain Humidity</b>	Baking pan from any local store	< \$2
<b>Electrical Supplies (wire, electrical tape, etc)</b>	Available in Clark 223	< \$5
<b>Misc (screws, double-sided tape, etc)</b>	Available in Clark 223 or readily available from personal supply	< \$5
<b>Total</b>		< \$215

## IMAGES AND CIRCUIT DIAGRAMS

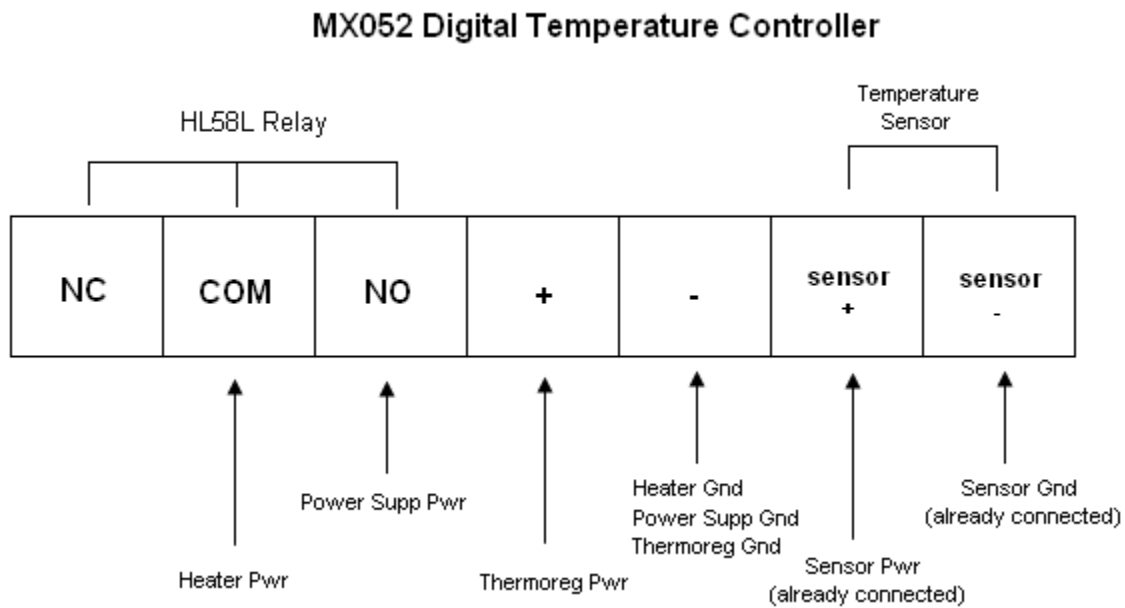
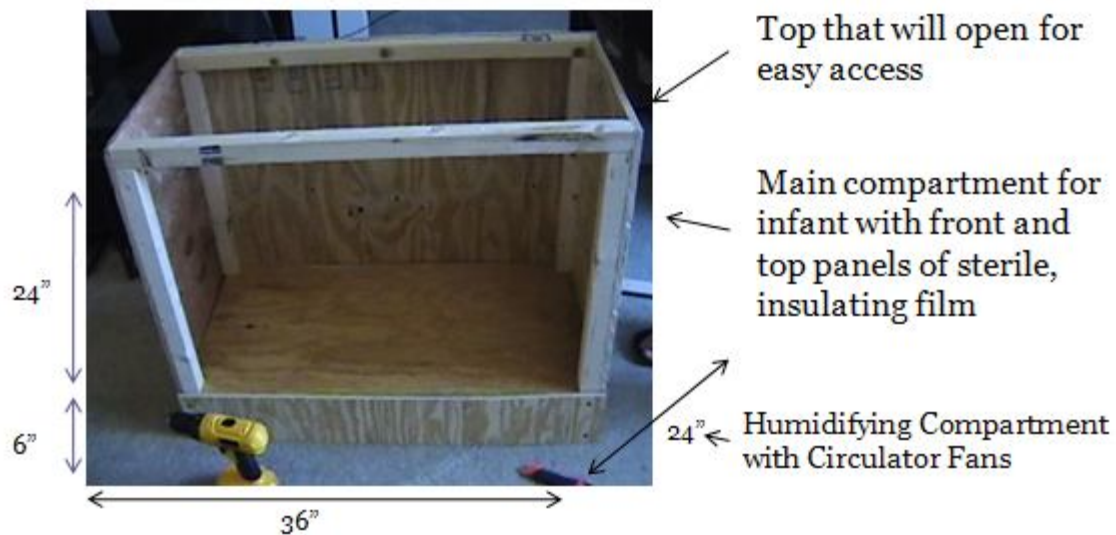


Fig. 8: Electronics set-up for the digital temperature sensor to the heater, fans, and temperature sensor.



## METHODS

### *A. Building the Wood Frame*

To build the wood frame, you must first start with the main compartment:

1. Attach one of the 22.5" length support wood pieces (up-and-down corner supports) to the left side (2" from the top) of one of the side panels (30" x 18"). Do the same thing to the other side panel, except for on the right side.
2. Attach these two support frames to the back panel, so that support wood is now in the back corners of the main component as shown in **fig. 8**.
3. Attach the two front supports (the remaining up-and-down corner supports) to the face of the incubator.
4. You can now turn the incubator upside-down and attach the main component bottom (34.5" x 18") to the four corners of these side supports.
5. Attach the two 35" front-and-back top support pieces to the top of the main frame.
6. Attach two 15" top side support pieces to the top of the incubator to complete the top frame.
7. Use the two 36" pieces along with the remaining two 15" pieces to make a rectangle. This will become the top of the incubator through which you will gain access to the infant.
8. Attach the access frame to the top of the main component using one of the sets of hinges, as shown in **fig. 7**.
9. Turn the incubator upside down and attach the two 5.5" support pieces to the front face of the humidifying compartment.

10. Connect the 36" x 6" panel to the front using the two remaining hinges.

11. Finally, cut square holes in the two sides of the incubator that will fit the fans.

### *B. Finishing the Frame and Adding Circulation Openings*

Once the frame is pieced together, you can drill holes (about ½" diameter) around the edges of the inside of the incubator with about 1" spacing between to allow for good air circulation while not compromising the strength of the wood. This can be seen in **fig. 6**, where holes were also placed over the area where the heater will blow warm air upwards.

Once this is finished, simply sand down the wood as desired and stain with NON-TOXIC preserving stain, such as Teak Oil, which will help to prevent molding while adding a finished look.

### *C. Insulating the Incubator*

You are now ready to add the insulation to the incubator. Apply sheets as desired to the walls of the inside of the incubator to add extra insulation. Place one sheet tightly over the access frame and one over the front of the main compartment. Make sure your seals are air tight by using a non-toxic adhesive or double-sided tape.

### *D. Calibrating the Temperature Sensor*

Talk about how to set room temp correctly, how to set min/max and what the positions on the switch do.



To calibrate the temperature sensor to the correct room temperature, apply 12 V to the "12V" point and adjust the 10K potentiometer until the voltage measured is 2.980 V. Then, connect the multimeter to pin 39 of IC2 L7107 and adjust VR5 until the voltage is 100 mV. The room temperature should now be set correctly.

To set the minimum temperature (the minimum temperature that should be maintained in the incubator), flip the switch to position C and adjust VR1 until you see the desired temperature (for the incubator should be around 36.5°C).

To set the maximum temperature (the maximum temperature that should be maintained in the incubator), flip the switch to position B and adjust VR2 until you see the desired temperature (for the incubator should be around 37.5°C).

#### *E. Connecting the Electronics*

The electronics should be connected as depicted in **fig. 8**. The power supply, power adapter for the thermoregulator, and the heater are stored under in the humidity compartment. Hide all wires behind the insulator in the incubator.

## **RESULTS**

We were able to produce a working incubator for a cost that would be less than \$215, if we needed to buy everything as opposed to getting most things for free.

The incubator was easy to assemble, after finding an optimal solution and can be easily replicated without much instruction.

Overall, this project was a great success, although the mean temperature and maximum range should still be tested over a long duration to make sure that the temperature remains at the desired level.

In the future, there are also some more adjustments that could be made to make this an even better product. One problem that is shared by modern incubators is the level of internal and external noise for the incubator. It would be best to reduce the noise inside by selecting the heater with the lowest amount of noise generated by the motor. Another addition to our particular incubator could be to deliver supplemental oxygen to the baby, if necessary.